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Physics Department
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PHYSICS DEPARTMENT
ANNUAL PROGRESS REPORT

1 January - 31 December 1971

edited by
H. Bjerrum Møller and C.J. Christensen

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CONTENTS

SUMMARY

The research work in the Physics Department at Risø covers five main fields.

Solid-state physics (neutron scattering)
Plasma physics
Nuclear spectroscopy
Radiation damage
Meteorology

The principal activities in these fields are presented in this report covering the period 1 January to 31 December 1971.

The solid-state physics section utilizes thermal neutron beams from the DR 3 reactor for experimental studies of solids. Five neutron spectrometers are available for these experiments: three triple-axis, one double-axis, and one multi-angle-reflecting crystal spectrometer with position-sensitive detector (MARX spectrometer). An additional diffractometer is used for structural studies by the Institute of Chemistry, University of Århus. The construction of the liquid-hydrogen cold source progressed, and installation in the DR 3 reactor is scheduled to take place in the summer of 1972. A new MARX spectrometer is under construction to be installed at one of the cold-neutron beams, while the other cold-neutron beam will later be utilized for experiments in an experimental hall under construction at the DR 3 reactor and connected to the cold-neutron source by neutron conducting tubes.

The scientific investigations fall within the following fields: magnetic structure, magnetic excitations, lattice dynamics, molecular dynamics, and amorphous structures.

The investigations of magnetic materials were continued during 1971, with special emphasis on the rare-earth metals and compounds. Magnetic structure investigations were performed on the light rare-earth metals and compounds Eu and CeSb, and the effect of magnetic fields on these structures was studied with the aim of clarifying the way in which the exchange and crystal fields determine the details of the magnetic structures.

The effects of changing the exchange and crystal field was also investigated in zero field by studying the magnetic structure of various alloys of Nd in dhcp Pr. Pure dhcp Pr was found not to order at temperatures down to 1.8 K, but the addition of small amounts of Nd stabilizes an ordered magnetic structure.

The dispersion relation for the magnetic excitons in the singlet ground state systems fcc Pr and Pr_3Tl was measured in a poly-crystalline sample. A minimum was found in the dispersion relation at Q = O as expected for ferromagnetic ordering, but the exciton energies were found to be nearly independent of temperature in disagreement with the theoretical current picture that the magnetic ordering should be driven by a softening of the excitons. The crystal field levels for the rare-earth pnictides (NdP, NdAs, and NdSb) were investigated by inelastic incoherent neutron scattering, and the magnetic moment and susceptibility was calculated, and existing data analysed. Experimental investigations of diluted rare-earth Al-alloys were also made.

The spin wave dispersion relation was measured in a single crystal of Ho, placed in a magnetic field strong enough to produce a ferromagnetic structure, for which measurements as well as analysis of the results in terms of exchange forces are easier and more reliable. The results were in agreement with previous measurements on the ferromagnetic alloy Ho-10% Tb, but a significant and unexplained deviation from the measurement on Ho in the spiral phase was found.

A theoretical investigation of the temperature dependence of the anisotropy constants for the heavy rare-earth metals was unitiated and the anisotropy constants for Tb were measured by studying the magnetic field dependence of the spin wave energy for long wavelength spin waves as a function of temperature. By extending this investigation to measurements as a function of magnon wave vector, the two-ion spin interactions were studied and found strongly anisotropic in Tb. A theoretical investigation of the two-ion spin interaction for both heavy and light rare-earth metals was also made. In order to facilitate the calculation of magnetic properties, the transformation properties of spherical harmonics, Stevens Operators, and Bose Operators were worked out. The magneto - elastic interaction in Tb was further investigated both experimentally and theoretically.

The two magnetic salts $RbNiF_3$ and FeF_2 were investigated. The dispersion relation for spin waves in the ferrimagnetic salt $RbNiF_3$ was measured. The data were analysed to give the exchange forces from which other magnetic properties were calculated. Further investigations of the temperature dependence of the spin wave energies in FeF_2 were carried out in order to make comparisons with recent theory.

The phonon dispersion relations were measured in a single crystal of para-H_2 by coherent neutron scattering, and the force constants, density of states, specific heat, Debye temperature, etc. were calculated from the neutron data. At higher phonon energies the neutron groups broaden considerably. An investigation of the large anharmonicity responsible for this effect was initiated. The aromatic compound d-$C_6D_4Cl_2$ was further investigated by incoherent inelastic neutron scattering. The results were found in agreement with calculations in the Pawley model using crystal potential parameters derived from experimental data for other aromatic compounds.

A neutron diffraction investigation of amorphous ice was initiated. Besides being of interest in itself, it may add to the understanding of the properties of liquid water, the structure of which is believed to be similar.

Various new experimental methods were investigated. A single crystal moving with the reflecting planes parallel to the incident neutron beam and scattering all incident neutron energies simultaneously through different scattering angles were studied, and a neutron diffraction method using fixed scattering angle was tested for possible use in diffraction from samples under high pressure.

The plasma physics section utilizes the following major pieces of equipment: a Q-machine, a puffatron, and a magnetically driven shock tube.

In the shock tube a strong shock moving at a constant speed is produced electromagnetically through the interaction between a constant driving current and its self-magnetic field. The velocity limitation of the current sheet was further studied, and it was shown that the Hall effect and the friction of the plasma against the electrode wall cause the limitation.

In the puffatron a rotating plasma is produced in an ExB configuration between two cylindrical electrodes. Studies of the energy distribution of the neutral particles emerging from the plasma showed that the energy distribution of the ions is as expected except for some particles with too high energies, possibly on account of instabilities.

The new solid-plasma interaction experiment was started in collaboration with Culham with a potential possibility of fuelling future fusionreactors in mind. A frozen-hydrogen pellet launcher has just been put into operation on the puffatron.

In the Q-machine Cs-atoms are ionized by impact on a hot Ta-plate. Confined radially by a constant magnetic field, a cold dc-plasma (Cs, T ~ 2000 K) is formed. Through studies of the ion velocity distribution resulting from a neutral-Cs beam interacting with the plasma, the charge exchange cross section between Cs and Cs^+ was measured. The propagation of ion acoustic perturbations was studied experimentally and theoretically. Step-function perturbations show experimental results that are well explained from the Vlasov-equation. A possible theoretical explanation of the heating of the solar wind was developed, using ideas from the Q-machine work.

The nuclear physics group is designing an experiment to look for the formation of fission isomers in neutron capture reactions at the DR3 reactor.

The radiation damage group has completed the stopping power measurements with measurements on a few new targetmaterials and with an extension of the energy range for some selected materials. In the course of time more than 20 metals have been studied.

The meteorology group is primarily engaged in studies of the planetary boundary layer, its main concern being the structure of boundary-layer turbulence. At Risø the group has at its disposal a 120 m steel tower in which routine measurements as well as experiments are carried out.

14 years of hourly readings of wind speed and direction, temperature, humidity, pressure, precipitation, now archived on magnetic tape, are being studied and applied in the pursuit of a variety of goals.

The analyses of cold- and hot-wire data from the 1968 Kansas experiment was completed. The results are consistent with results obtained by the other groups which participated in the experiment.

The problems that arise in statistical analysis of the results of turbulence measurements have led to extensive studies of stochastic processes. Important questions in connection with digital and analog computation of energy spectra have been investigated for the stationary case, and a computionally feasible definition of an evolutionary energy spectrum has been developed for non-stationary ensembles of records of finite lenght.

This year, as earlier, the meteorology group undertook a number of tasks of an applied nature. Among these were: site evaluation and dispersion modelling, development and testing of meteorological instruments, air pollution meteorology, and dynamical effects of wind on building structures.

1. SOLID STATE PHYSICS (NEUTRON SCATTERING)

Magnetic Properties of Metallic Europium

(A.H. Millhouse)

A single crystal of europium was studied in the temperature range 4.2 K to 100 K and in applied magnetic fields up to 42 kOe. In the absence of an applied field, europium is antiferromagnetic below T_N = 90.5 K. The antiferromagnetic structure is a helix with axes along $\langle 1,0,0 \rangle$ directions and an interlayer turn angle of 52^o at T_N. The transition at T_N is first order with the magnetization decreasing from 40 % of its saturation value to zero at T_N. The application of a magnetic field along one of the helix axes at 4.2 K suppresses the modulation along [1,0,0] directions normal to the applied field. This suppression is complete at 7 kOe and remains after reduction of the applied field to zero (fig. 1). If the sample is then warmed the modulation along those [1,0,0]

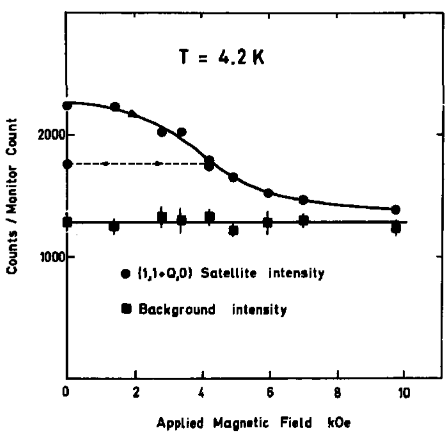

Fig. 1. Magnetic field dependence of the intensity of the (1,1+Q, 0) satellite at 4.2 K in Eu. The dashed line shows the hysteresis exhibited by the sample when the magnetic field is reduced from 4 kOe to zero.

directions normal to the applied field reappears at 35 K. The application of a magnetic field along a [1,1,0] direction at 4.2 K suppresses the modulation along the [1,0,0] direction normal to the field and is complete at 5 kOe. Above 5 kOe the intensities of magnetic satellites, caused by modulation along the other two [1,0,0] directions decrease but do not disappear in applied fields up to 20 kOe. No ferromagnetic components were observed with an applied magnetic field up to 42 kOe in either the [1,0,0] or [1,1,0] direction. None of the expected structure models, distorted helix fan, longitudinal modulation, tilted helix, or cone, explain the satellite intensities observed with high magnetic fields.

Magnetic Structures of CeSb in Strong Magnetic Fields
(P. Fischer, B. Lebech and B.D. Rainford)

Neutron diffraction measurements on single crystals of CeSb showed a first-order transition to an antiferromagnetic phase at 16.0 K, corresponding to the appearance of a slight tetragonal distortion of the rock salt structure. Between T_N and 4.2 K five antiferromagnetic phases I, II, III, IV, V (fig. 2) were observed in zero external magnetic field. The ordered magnetic moments are confined to the $\langle 1,0,0 \rangle_{cubic}$ easy directions of magnetization and modulated according to cosine waves with the modulation vector along equivalent $\langle 1,0,0 \rangle$ directions. The magnitudes of the fundamental modulation vectors Q are in general incommensurate.

In the commensurate high temperature phase I ($\bar{Q} = \frac{1}{3}\ \bar{\tau}_{2,0,0}$) and in the low temperature phase V ($\bar{Q} \simeq \frac{1}{4}\ \bar{\tau}_{2,0,0}$) we observe a single set of satellite reflections around nuclear reciprocal lattice points, suggesting a simple cosine modulation. In the intermediate temperature region additional weak satellites are present which indicate higher harmonics in the modulation of the magnetic moments.

When a magnetic field is applied in a [1,0,0] direction at 4.2 K, a single domain is formed at 10 kOe. Above 10 kOe the intensity of the preferred antiferromagnetic satellite with the modulation wave vector along the field gradually decreases until the satellite disappears rather abruptly at 23 kOe. When the field is decreased from 40 kOe the preferred satellite reappears at 16 kOe. The satellite intensity increases slowly until the satellite disappears again at 5 kOe. Simultaneously the satellites with modulation wave vector perpendicular to the field reappear. However, the total intensity in the satellites corresponding to the fundamental $\bar{Q}$ at zero field is lower than in the virgin sample. This indicates that

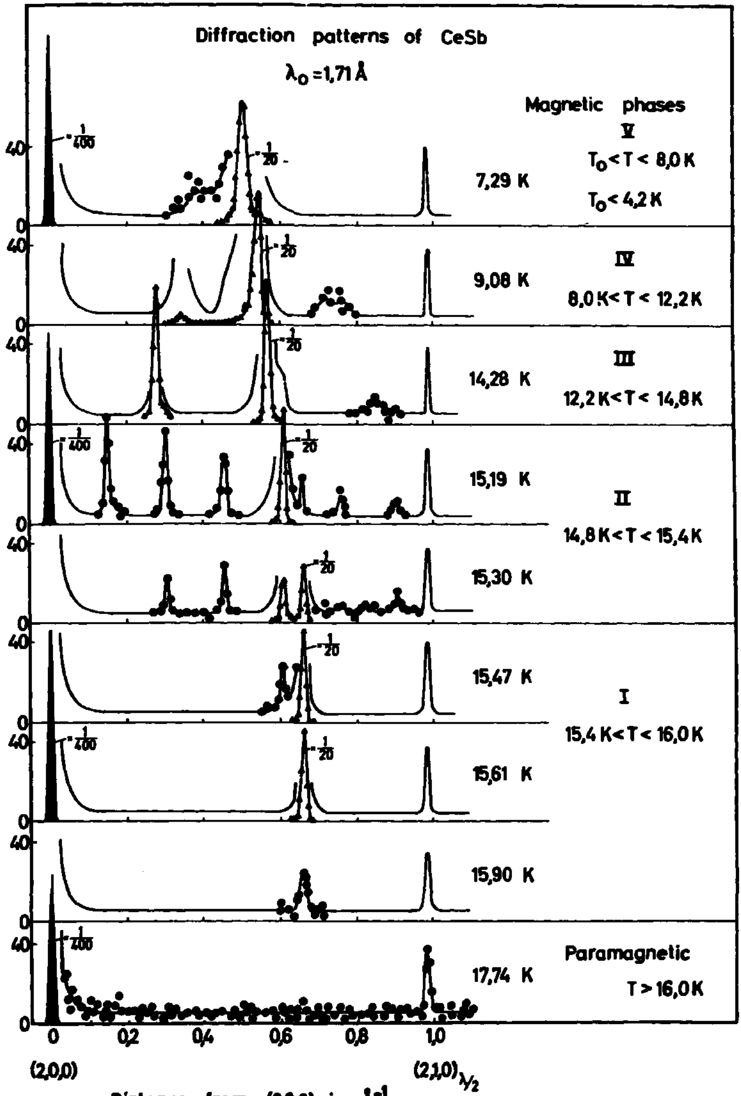

Fig. 2. Scan from the (2, 0, 0) to the (2, 1, 0) reciprocal lattice points in CeSb, showing the diffraction patterns observed in zero field in the paramagnetic phase above 16 K and the five magnetic phases (I-V) below 16 K.

an external field of 40 kOe induces a permanent change of the magnetic structure at 4.2 K.

While applying a magnetic field along a $[1,\bar{1},0]$ we could measure the weak nuclear reflections (h,k,l, all odd). At 4.2 K the satellites with modulation wave vectors at 45° to the field disappeared at 15 kOe, and a weak ferromagnetic component was observed. It increased slowly until 31 kOe where the ferromagnetic component increased by 0.3 μ_B. Most of the observed transitions correspond to the steps observed in the magnetization data of a single crystal CeSb by Busch and Vogt[1].

Magnetic Structures of Single Crystals of Pr and Pr-Nd Alloys

(B. Lebech)

Pr and Nd have the double hexagonal, close-packed structure in which there are two types of sites with cubic and hexagonal environment respectively.

In Nd the two types of sites order into periodic antiferromagnetic structures at different temperatures and with different periodicities and moment directions. Upon application of a magnetic field, the structures change in a complicated way [54].

Previous neutron diffraction studies [54] of a single crystal of Pr showed no magnetic ordering down to 4.2 K in zero applied field. Systematic scans at 4.2 K along the three principal axes through the (0,0,1) and (0,0,3) reciprocal lattice points showed neither ferromagnetic nor antiferromagnetic order. Upon application of a strong magnetic field in either the b_1- or the b_3-directions of the crystal, a ferromagnetic moment was induced.

Similar scans at 1.8 K parallel to the [1,0,0] direction in the reciprocal space through the (0,0,1) and (0,0,3) reciprocal lattice points showed no antiferromagnetic order (fig. 3). Within the experimental error the intensities of several nuclear peaks observed at 4.2 K and 1.8 K remained unchanged.

By studying the behaviour of Pr-Nd alloys one may investigate the effect of varying exchange and crystal fields over this system. Two alloy single crystals have been studied so far. In a 5.6 % Nd-94.4 % Pr alloy the hexagonal sites order at 6.5 K (fig. 3) in a periodic structure like that of Nd. The modulation wave vector decreases from 0.240 $Å^{-1}$ at 6.5 K to 0.235 $Å^{-1}$ at 2.6 K, and the amplitude saturated at 0.9 μ_B.

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[1] G. Busch and O. Vogt, Phys. Rev. Letters 25A, 449 (1967)

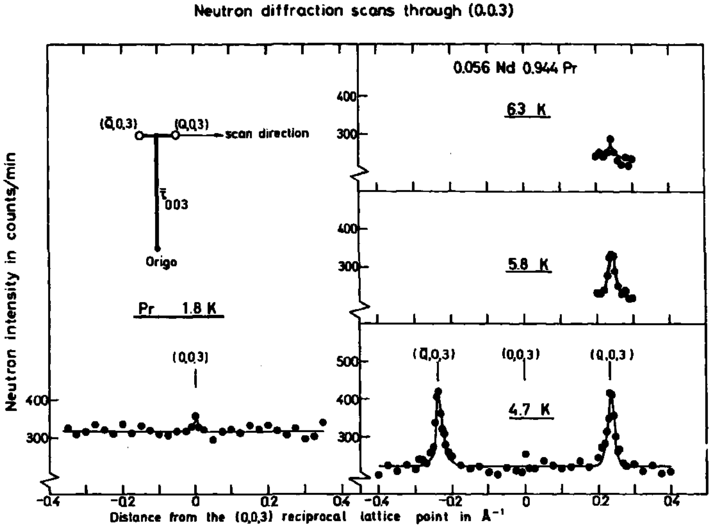

Fig. 3. Neutron diffraction scans parallel to the [1,0,0] direction through the (0,0,3) reciprocal lattice point for Pr and 5.6 % Nd-94.4% Pr single crystals in zero applied magnetic field.

Further addition of Nd increases the Néel temperature. The hexagonal sites order at 12 K in a 27% Nd-73% Pr alloy in agreement with the magnetization data of McEwen [1], and the modulation wave vector decreases like that of pure Nd from 0.260 $Å^{-1}$ at 10.5 K to 0.247 $Å^{-1}$ at 4.2 K. The amplitude saturates at 1.5 μ_B. No order was observed at the cubic sites down to 1.8 K.

Magnetic Form Factor of Pr

(B.D. Rainford (Imperial College), F.A. Wedgwood (Harwell), and B. Lebech)

Pr has the double hexagonal close-packed structure in which there are two types of sites with cubic and hexagonal environment respectively. The magnetic form factor for the hexagonal sites was measured, using one of the polarized neutron spectrometers at Harwell. The form factor measured by means of polarized neutrons agrees with the previously measured form factor [54] within the experimental accuracy.

[1] K.A. McEwen, Conference Digest No. 3. Rare Earths and Actinides, Durham, 35 (1971).

Magnetic Excitons in dhcp Pr

(J. Gylden Houmann and B.D. Rainford)

In the light of a recent analysis [1] of the single crystal susceptibility results we can assign the wave functions in the transition on the hexagonal sites in dhcp Pr as

$|g\rangle = |m_j = 0\rangle$ ground state (singlet)
$|e\rangle = |m_j = \pm 1\rangle$ excited state (doublet)

The transition between these states is then the only allowed transition on the hexagonal sites at low temperatures.

The Hamiltonian may be written

$$H = V_c - \sum_{i>i'} \mathcal{J}_{ii'} \bar{J}_i \cdot \bar{J}_{i'} - \sum_{j>j'} \mathcal{J}_{jj'} \bar{J}_j \cdot \bar{J}_{j'} - \sum_{i>j} \mathcal{J}_{ij} \bar{J}_i \cdot \bar{J}_j \qquad (1)$$

where V_c is the crystal field potential, and the indices i and j refer to atoms on the two sublattices of the hcp lattice. We find two doubly degenerate branches with energies

$$E_q = \{ \Delta^2 - \alpha^2 \Delta [\mathcal{J}(q) \pm \mathcal{J}'(q)] \}^{\frac{1}{2}} \qquad (2)$$

where $\mathcal{J}(q)$ and $\mathcal{J}'(q)$ are the Fourier transforms of the exchange integrals $\mathcal{J}_{ii'}$ and $\mathcal{J}_{ij}$, respectively. α is the crystal field splitting, and Δ is the matrix element of J^+ or J^- between $|g\rangle$ and $|e\rangle$. Δ cannot be determined directly from the experimental data. However, the measurements in an applied magnetic field [2] [64] give additional information and allow us to determine Δ as 2.14 ± 0.10 meV. The value of Δ was used together with eq.(2) to determine the Fourier-transformed exchange parameters, $\mathcal{J}(q)$ and $\mathcal{J}'(q)$, for the hexagonal sites [64]. The observed splittings of the branches were ignored in this calculation.

We plan to study experimentally in the near future the temperature and field dependence of the excitations, using a larger single crystal sample.

Magnetic Excitons in Singlet Ground State Ferromagnets

(R.J. Birgeneau, E. Bucher (Bell Labs.), and J. Als-Nielsen)

It has been recognized for a number of years that the magnetic properties of singlet ground state systems in which the exchange field and the crystal field nearly balance differ in a fundamental way from

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[1] Risø Report No. 237 p. 12 (1971)

[2] B.D. Rainford, to be published.

those of conventional magnets. In particular, magnetic ordering occurs as a result of a polarization instability of the ground state wave function rather than through the alignment of permanent moments. The magnetic excitations in this case are single ion crystal field transitions which propagate through the lattice via the exchange; these excitons should be well-defined in both the paramagnetic and ordered regime. Recently it has been proposed that the phase transition is actually driven by a softening of the magnetic exciton at the Q-vector appropriate to the magnetically ordered phase, in analogy with soft phonon modes observed in certain structural phase transitions. The dynamics in the singlet ground state systems fcc Pr and PrTe, was studied [41]. The neutron scattering experiments were made with polycrystalline samples so that all experiments were performed around the (0,0,0) reciprocal lattice point, thus yielding a spherically-averaged dispersion relation. Well-defined excitons, corresponding to transitions between the Pr^{+++} Γ_1 ground state and the Γ_4 excited triplet, are observed in both paramagnetic and ordered regimes. In both fcc Pr and Pr_3Tl the exciton dispersion has its minimum at or near Q = 0 as expected for ferromagnetic ordering. The dispersion curves for both materials are given in fig. 4. However, the exciton energies are found to be nearly temperature independent (fig. 5), in striking disagreement with the existing theory.

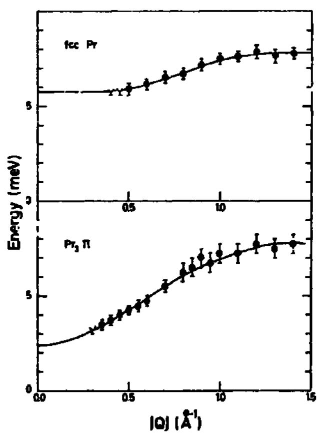

Fig. 4. Γ_1 - Γ_4 spherically averaged exciton dispersion relations in fcc Pr and Pr_3Tl; the dispersion relations are independent of temperature up to 60 K, above which temperature the excitons are no longer observable.

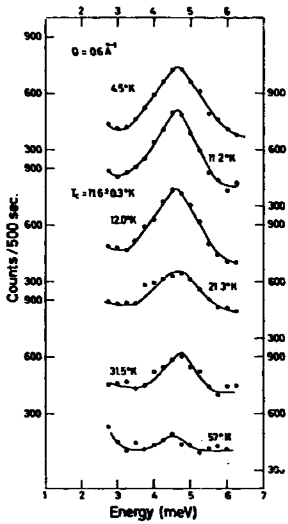

Fig. 5. Typical exciton scans in Pr_3Te as a function of temperature. Similar behaviour is observed at all other wave vectors in both Pr_3 and fcc Pr.

Crystal Field Transitions in Rare Earth Alloys

(A. Furrer and J. Kjems)

During the course of the measurements several improvements of the MARX spectrometer were made with better intensity and resolution as a result. Graphite monochromators, analysers, and filters were used as well as cooled Be-filters. We were thus able to observe well resolved crystal field transition peaks in the energy transfer range from 1 to 20 meV, using polycrystalline samples which generally were kept at 100 K.

A series of measurements on Nd-group V compounds (NdP, As and Sb) were made, and the level schemes were deduced from the peak positions and intensities using the Lea, Leash and Wold diagrams (fig. 6). The level sequence with increasing energy is $\Gamma_8^{(2)}$-quartet, Γ_6-doublet, and $\Gamma_8^{(1)}$-quartet, and the splitting varies with lattice distance as expected from the point charge model.

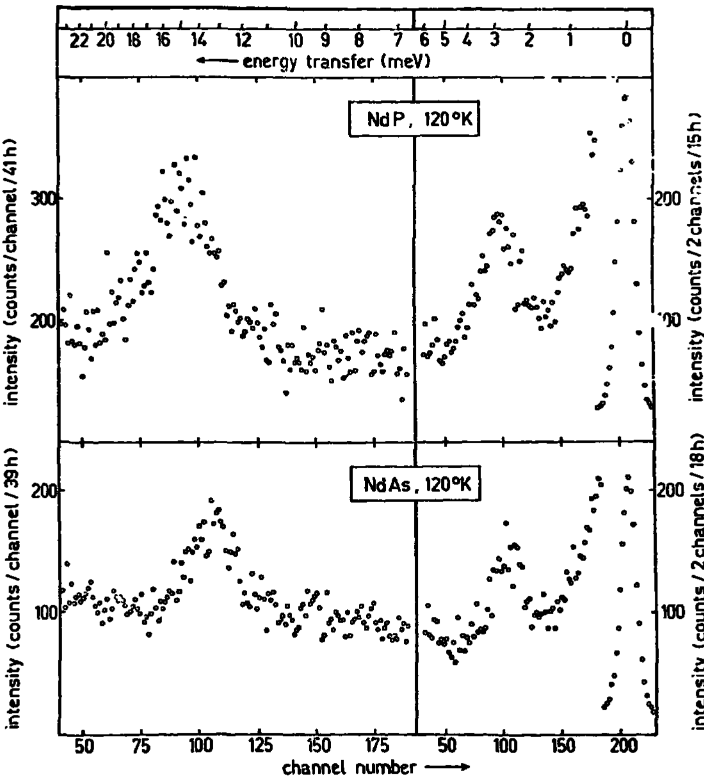

Fig. 6. Crystal field transitions in NdP and NdAs as measured with the MARX-1 spectrometer. The intense high and low energy transitions are $\Gamma_8^{(1)} - \Gamma_8^{(12)}$ and $\Gamma_6 - \Gamma_8^{(2)}$ respectively.

Several diluted rare-earth-Al_2 alloys were also investigated. Well resolved peaks were observed in $Tm_{.25}Y_{.75}Al_2$ and in $Er_{.15}Y_{.85}Al_2$ and some structure in the broad magnetic scattering from $Pr_{.20}Y_{.80}Al_2$. The measurements will be continued in order to make unambiguous assignments of the observed spectra.

Preliminary investigations were made on CeBi and $Ce_{.5}Y_{.5}Sb$, and in the latter a well resolved peak corresponding to the only transition was observed.

Magnetic Properties of Rare Earth Pnictides
(P.-A. Lindgård and P. Bak)

The magnetic moments, the quadropole moments, and the high- and zero-field susceptibilities were computed for the rare-earth pnictide series. Existing data on these quantities and on energy levels determined by neutron scattering were analysed. The influence of two-ion-anisotropic interaction was investigated. Part of this work was carried out by P. Bak in preparation for his master's thesis.

The Spin Wave Dispersion Relation in Ferromagnetic Ho
(J. Gylden Houmann and P. Touborg, DtH)

Ho has a helical magnetic structure below 133 K with a spiral wave vector Q of about 0.22 $Å^{-1}$. However, the application of an external magnetic field can change the structure from helical to ferromagnetic. At 4.2 K a field of approximately 5 kOe is needed to create ferromagnetic ordering. Also alloying of Tb into Ho gives a ferromagnetic structure below a certain temperature. Spin waves have previously been measured in a Ho-10% Tb alloy [1].

The magnon dispersion relations for the a- and c-directions in ferromagnetic Ho were measured at 4.2 K by means of inelastic neutron scattering. The results shown in fig. 7 are similar to those from Ho-10% Tb [1].

Consequently the exchange interaction $\mathcal{J}(\bar{q})$ is very similar to that reported for Ho-10% Tb; however, for $\bar{q}$ along the c-direction the maximum value $\mathcal{J}(\bar{Q})$ is somewhat larger than in Ho-10% Tb. This reflects the stronger tendency to form a spiral structure in pure Ho than in Ho-10% Tb. There is a significant discrepancy between $\mathcal{J}(\bar{q})$ for $\bar{q}$ along the c-direction determined in this experiment and $\mathcal{J}(\bar{q})$ as measured in the spiral magnetic phase of Ho [2]. This discrepancy is not yet understood. The present experiment was performed on a 7.5 mm sphere of single crystalline Ho. A larger crystal is being prepared, and measurements of the magnetic field dependence of the dispersion relation are planned in order to study the magnetic anisotropy forces in Ho.

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1) H. Bjerrum Møller, M. Nielsen and A.R. Mackintosh, Exchange Interaction in Rare Earth Metals, Proceedings of a Conference on Rare Earth Metals, Paris-Grenoble, France, 1969.

2) R.M. Nicklow, J. Gylden Houmann, H.A. Mook (to be published)

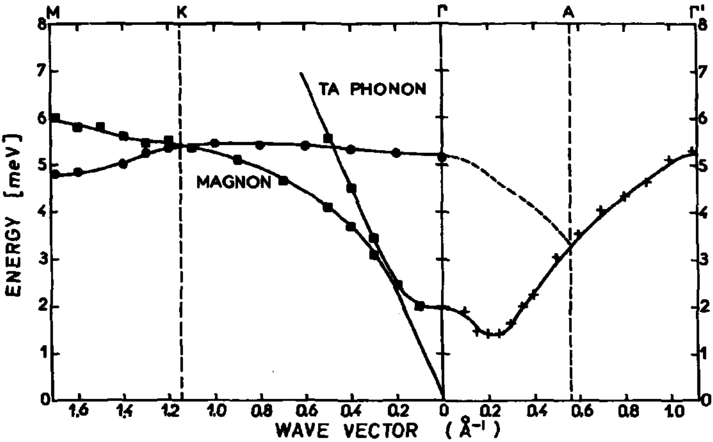

Fig. 7. Magnon dispersion relation in ferromagnetic Ho at 4.2 K (internal field H_i = 7 kOe).

<u>Temperature Dependence of Spin Waves and Anisotropy Constants</u>
(P.-A. Lindgård and O. Danielsen)

A number of thermodynamic methods were used and compared in investigating the temperature dependence of spin waves and anisotropy parameters in systems with anisotropic exchange interaction and a strong single-ion anisotropy. In one method, the single-site approximation, the density matrix used in evaluation of traces is truncated into that for a single site. The second method utilizes a spin wave expansion of the Hamiltonian. Both methods give deviations from the $l(l+1)/2$ law for the temperature dependence of an anisotropy constant of order l. An explicit evaluation of the temperature laws for comparison with the experimental results on terbium is in progress.

Anisotropic Two-Ion Interaction in Rare Earth Metals

(P.-A. Lindgård)

The interaction between two magnetic moments $\bar{J}_i$ and $\bar{J}_j$ separated by a vector $\bar{R}_{ij}$ in a rare earth compound is not well represented by the isotropic Heisenberg Hamiltonian $H = -\sum_{i,j} K(R_{ij})\, \bar{J}_i \cdot \bar{J}_j$. The most general anisotropic two-ion interaction is conveniently expressed in terms of tensor operators:

$$H = -\sum_{i,j} \sum_{l,m} \sum_{l'm'} K_{lm}^{l'm'}(\bar{R}_{ij})\, \tilde{O}_{lm}(i)\, \tilde{O}_{l'm'}(j) \qquad (1)$$

Physical mechanisms which may contribute to such an interaction were investigated, and the qualitative effects on the magnon dispersion curves and on the intensity of scattered neutrons were analysed. It should be noted that it is possible experimentally to differentiate between an interaction which depends or does not depend on the projection of $\bar{J}_i$ and $\bar{J}_j$ on $\bar{R}_{ij}$. In other words it is possible qualitatively to determine whether $K(\bar{R}_{ij})$ depends essentially on the direction of $\bar{R}_{ij}$. A coupling of directions in the spin space with directions in the real space gives rise to a lifting of certain symmetry-determined degeneracies of spin wave branches in the Brillouin zone.

Contributions to the directional-dependent interaction may originate from classical- and pseudo-multipolar interactions intermediated by photons, electrons, or phonons. The effect of this type of interaction was observed in terbium as a splitting along the K-H edge. The order of magnitude of the Kaplan - Lyons interaction agrees, the classical multipole interaction is too small.

Contributions to the non-directional interaction may originate from two-ion magneto - elastic terms or anisotropy terms in the Ruderman - Kittel interaction on account of a magnetic splitting of the Fermi surface. A numerical estimate of the latter effect is being made. Effects of such an interaction were also observed in terbium in the spinwave - magnetic field experiment.

Also in the light rare earth praseodymium effects of two-ion anisotropy are observed in the excitation spectrum.

It has previously been pointed out that it is not possible to determine the complete two-ion Hamiltonian (1) from low-temperature spin wave measurements. Analysis is more conveniently done using the effective Hamiltonian

$$H = \sum_{i,j} \sum_{\alpha,\beta} K^{\alpha\beta}(\bar{R}_{ij})\, J_i^{\alpha} J_j^{\beta} \qquad (2)$$

Magnetic Anisotropy in Tb

(H. Bjerrum Møller, J. Gylden Houmann, and J. Jensen)

The magnetic anisotropy of Tb was measured by studying the dependence of the magnon energies on magnetic field.

The results obtained at zero wave vector (fig. 8a) allows a determination of the single-ion anisotropy parameters shown in fig. 8b.

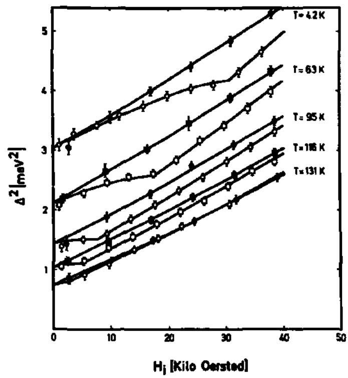

Fig. 8a. The dependence of the square of the magnon energy gap on internal magnetic field in Tb. Open symbols represent results for the field in the hard direction, and closed the easy directions. The full lines are least-squares fits of the theoretical expressions to the experimental results.

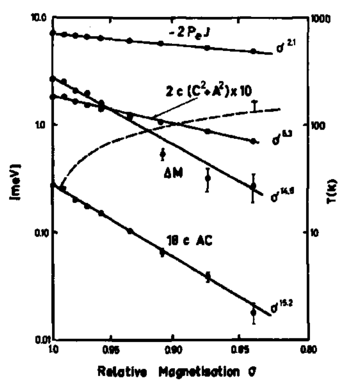

Fig. 8b. The single-ion anisotropy parameters in Tb, as a function of relative magnetization.

The parameter $P_e J$ is the 2-fold single-ion anisotropy, but includes also contributions from anisotropic two-ion interactions, while the remaining three parameters are of magneto - elastic origin [1]. The six-fold, single ion anisotropy was found small compared with the other contributions and could therefore not be determined from the experimental data. The dependence of the anisotropy parameters on the relative magnetization follows closely the theoretical prediction of Callen and Callen [2]. There is general agreement between the magnitudes of the anisotropy parameters deduced from our results and from macroscopic measurements [3], although there are quantitative discrepancies, especially in the magnetostriction coefficients, which deserve further study.

A study of the field-dependence of the magnon energies for different q-values gives explicit information about the anisotropic coupling between moments on different sites. Measurement with a magnetic field in the direction of easy magnetization allows a determination of interaction constants of the two-ion spin Hamiltonian

$$
\begin{aligned}
H = & \sum_{i>j} \left[\mathcal{J}_{ij}^{aa} (J_{i\xi} J_{j\xi} + J_{i\eta} J_{j\eta}) + \mathcal{J}_{ij}^{cc} J_{i\zeta} J_{j\zeta} \right] \\
& - \sum_{i>j} \Big\{ \sqrt{3}\, D_{ij}^{\alpha}\, \bar{\varepsilon}^{\alpha} \left[J_{i\zeta} J_{j\zeta} - \tfrac{1}{3} \bar{J}_i \cdot \bar{J}_j \right] \\
& - D_{ij}^{\gamma} \left[(J_{i\xi} J_{j\xi} - J_{i\eta} J_{j\eta})\, \bar{\varepsilon}_1^{\gamma} + (J_{i\xi} J_{j\eta} + J_{i\eta} J_{j\xi})\, \bar{\varepsilon}_2^{\gamma} \right] \Big\}
\end{aligned}
$$

where the notation is that of ref. [1]

The first term (square brackets) is the anisotropic exchange interaction, and the other two terms represent two-ion magneto-elastic interactions. The first of the latter two have the same form as the anisotropic exchange and we shall therefore include it by an appropriate redefinition of the parameters ($\mathcal{J}_{ij}$). In the experiment we determine $[\mathcal{J}^{cc}(0) - \mathcal{J}^{cc}(q)]$ and $[K^{aa}(0) - K^{aa}(q)] = [\mathcal{J}^{aa}(0) - \mathcal{J}^{aa}(q)] - c\,[D(0) - D(q)]$ where $\mathcal{J}^{aa}(q)$, $\mathcal{J}^{cc}(q)$ and $D(q)$ are the Fourier transforms of $\mathcal{J}_{ij}^{aa}$, $\mathcal{J}_{ij}^{cc}$ and D_{ij}^{γ} respectively. The results are shown in fig. 9.

---

[1] H. Bjerrum Møller, J. Gylden Houmann, J. Jensen and A.R. Mackintosh (to be published in the Proceedings of the Symposium of Neutron Inelastic Scattering IAEA 1972.

[2] H.B. Callen and E. Callen, J. Phys. Chem. Solids 27, 1271 (1966)

[3] J.J. Rhyne, Magnetic Properties of Rare Earth Metals (R.J. Elliot, Editor), Plenum Press, London (1972).

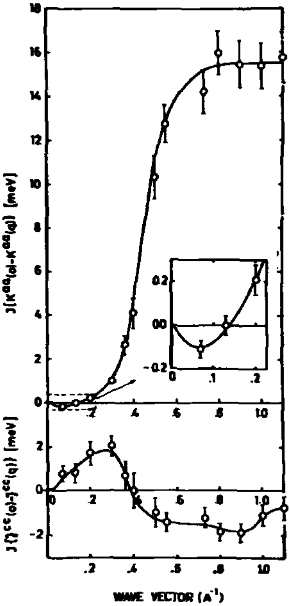

Fig. 9. The Fourier transforms of the effective two-ion coupling between moments, for the c-direction of Tb at 4.2 K.

It is immediately obvious from this figure that the coupling between the moments *is highly anisotropic*, but whether this anisotropy arises primarily from anisotropic exchange or from two-ion magneto - elastic effects is not yet clear. Further experiments on the temperature dependence of the coupling between the moments should help to elucidate this question, while measurements with a field along the hard direction will allow the anisotropy in the plane to be studied.

Spherical Harmonics, Tensor Operators and Bose Operators
(O. Danielsen and P.-A. Lindgård)

The interrelations and the transformation properties under rotations of the spherical harmonics, tensor operators, Stevens operator equivalents, and Bose operators were worked out in detail. The purpose is to develop formulae and tables which facilitate calculation of the magnetic properties of systems with complicated interaction forces. Tables of rotation matrices and 3_j-symbols have been computed and compiled in a Risø Report (to be published).

Magneto - Elastic Interactions in Terbium and the Elastic Properties of Terbium
(J. Jensen)

Further calculations were performed, making use of the Hamiltonian for linear magneto - elastic coupling proposed by Callen and Callen. We generalized this Hamiltonian to take into account dynamic interactions between spin waves and long wave lenght phonons. These calculations are in fair agreement with experimental results.

The magneto - elastic contribution to the spin wave energy gap at zero wave vector was found to be practically independent of magnon - phonon interactions (or of the relaxation of the lattice), contrary to the "flexible lattice" calculations performed by Cooper.

The same Hamiltonian expanded to include explicitly the relative displacements of neighbouring ions also gives an adequate account of the magnon - phonon interactions at short wave lengths which were observed in terbium by means of inelastic neutron scattering. However, this linear theory cannot explain the interaction between the acoustic magnons and the optical transverse phonons in the c-direction of terbium.

Further experimental investigation of this interaction in terbium at 4.2 K removed any doubt about the existence of the interaction which gives rise to an energy gap equal to 1.35 meV at $q = 0.45$ Å^{-1}.

The four elastic constants c_{11}, c_{33}, c_{44}, and c_{66} of terbium were measured by an ultrasonic pulse echo technique as functions of temperature (150 - 300 K). Strong coupling between the lattice and the spin system was observed in the neighbourhood of the transition temperatures, T_N and T_C.

Spin Waves in the Ferrimagnet $RbNiF_3$
(J. Als-Nielsen and R. J. Birgeneau)

Among magnetic materials the magnetic salts are particularly simple. The moments of magnetic ions are coupled by superexchange via intervening non-magnetic anions. A wealth of experimental information including spin wave spectra from neutron scattering has been obtained within the last decade from simple antiferromagnets (e.g. $RbMnF_3$, MnF_2) and also recently from simple ferromagnets (e.g. EuO, EuS). However, the simplest possible ferrimagnet with two up-spins and one down-spin in a unit cell has not been investigated until the present study of $RbNiF_3$. The magnetic structure of $RbNiF_3$ is shown in the left part of fig. 10. Along the c-axis we have the simple two-up, one-down spin structure, but in general there are 6 magnetic ions per unit cell. The spin wave spectrum obtained from our inelastic neutron scattering study is shown in the right part of fig. 10. The spectrum can be accounted for by only two exchange interactions: nearest neighbour B-B interaction between B atoms in successive plans and similarly A-B interaction between A and B atoms in successive planes. The calculated spin wave dispersion curves shown as full lines in fig. 10 result from a

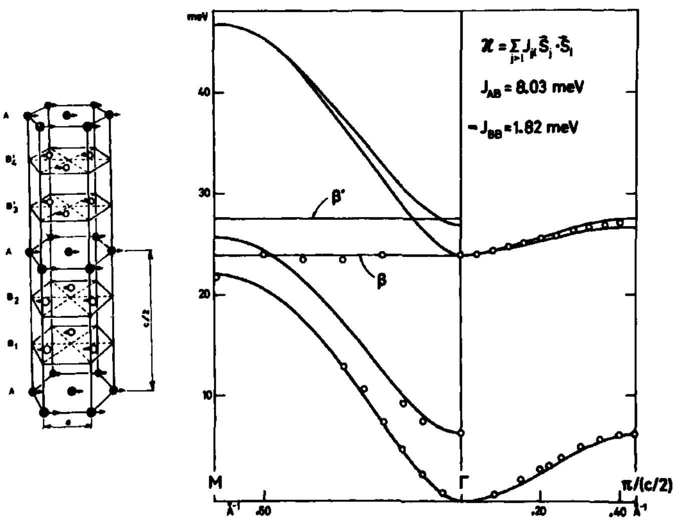

Fig. 10. Magnetic structure of $RbNiF_3$ (left) and the spin wave dispersion curves for propagation in the basal plane (middle) and along the c-axis (right). The full lines are calculated dispersion curves with nearest-neighbour interactions between AB and BB pairs only.

solution of 6 equations of motions of the spins in a unit cell, and the calculation involves numerical diagonalization at each q-vector of a 6 x 6 matrix.

The flat dispersion curves (β and β') correspond to particularly simple modes in which the A spins do not move at all. In the lower mode (β) a B_2 spin moves in the exchange field of 3 A spins, while B_1 follows B_2 in phase. B_3' moves with the same amplitudes as B_2, but 180^o out of phase. Evidently, excitation of this mode costs an energy of $3J_{AB}$. In the upper flat mode (β') B_1 and B_2 are 180^o out of phase as are B_3' and B_4', so that excitation of this mode costs an additional energy of $2J_{BB}$.

The antiferromagnetic exchange coupling between A and B ions was found to be considerably stronger than the ferromagnetic coupling between B ions. This difference in magnitude of J_{AB} and J_{BB} is simplified by the difference in co-ordination numbers, 6:1, so that the exchange field $H_{AB}(A)$ on an A ion owing to the AB exchange is 27 times larger than the corresponding exchange field $H_{BB}(B)$. Thus $RbNiF_3$ may be pictured as a set of "two-dimensional ferrimagnets" composed of three successive planes BAB', coupled internally by H_{AB}, which are then aligned relative to each other by the much smaller exchange field H_{BB}.

This picture was confirmed by the observed renormalization of the spin wave energies as the temperature is raised towards the Curie temperature T_c = 133 K. The acoustic magnons propagating in the c-direction renormalize as the sublattice magnetization, whereas the flat optical magnons propagating in the hexagonal plane only renormalize by about 4 % in going from 4.2 K up to T_c.

We found that other magnetic properties such as the high temperature susceptibility, sublattice magnetization in a field, and two-magnon Raman scattering may be quantitatively understood in terms of the exchange constants from the neutron scattering experiment. Finally, it should be noted that this experiment provides results in one system for 90^o and 180^o superexchange paths in the Ni-F-Ni complex, which is of interest for the theory of superexchange.

Magnons in FeF_2

(J. Gylden Houmann and B. D. Rainford)

The experiment was concluded with additional measurements at intermediate temperatures between 4.2 K and 50 K [1], and at temperatures close to the Néel temperature.

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[1] Risø Report No. 237, January 1971, page 18.

The data are being corrected for resolution effects in order to extract the intrinsic lifetime of the spin waves.

As has earlier been reported, pronounced magnon - phonon interaction was observed in FeF_2. In order to make a detailed comparison between this experimental observation and recent theory [1], the low-energy part of the acoustic phonons in FeF_2 have been measured at room temperature for the $\langle 1,0,0 \rangle$ and $\langle 0,0,1 \rangle$ directions.

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[1]) S.W. Lovesey, Theory of Magnon and Phonon Interaction in FeF_2 (to be published in the proceedings of 17th Conference on Magnetism and Magnetic Materials 1972).

Phonons in Solid Hydrogen and Deuterium Studied by Inelastic Coherent Neutron Scattering

(M. Nielsen)

Phonon dispersion relations were measured by coherent neutron scattering in solid para hydrogen and ortho deuterium (fig. 11). The phonon

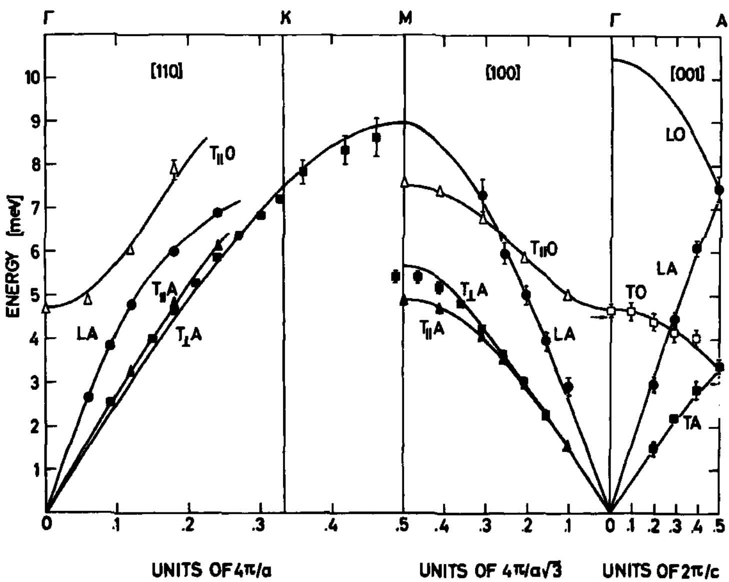

Fig. 11. Phonon dispersion relations for p-H_2 at 6 K and zero pressure. The full lines are the results of the Born von Karman fit where a third-nearest neighbour general force model is used. The arrow at Γ shows the frequency of the TO mode as derived from Raman spectroscopy.

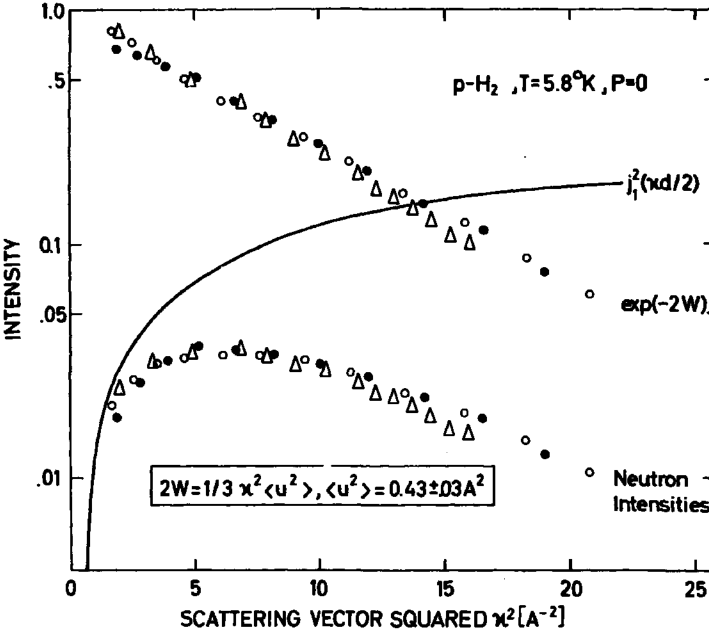

Fig. 12. Debye-Waller factor for p-H_2 at 5.8 K. Neutrons are scattered incoherently in pure p-H_2 by exciting the rotational energy levels of the molecules. The lower points in the figure show the intensity of J = 0 to J = 1 scattering with no energy exchanged with the lattice. This intensity is proportional to the Bessel function squared j_1^2 ($\varkappa$d/2) and to the Debye-Waller factor e^{-2w}. $\varkappa$ is the neutron scattering vector, and d is the separation of the atoms in the molecule.

energies were found to be nearly equal in the two solids, the highest energy in each case lying close to 10 meV. The line widths of the phonons are much larger in hydrogen than in deuterium, and for this reason is was not possible to measure the higher phonon energies in hydrogen.

The pressure and temperature dependence of the phonon energies was measured in ortho deuterium and the lattice change determined by neutron diffraction. By the application of a pressure of 275 bars the phonon energies are increased by about 10 per cent, and heating of the crystal to near the melting point decreases the phonon energies by about 7 per cent.

The density of states, the specific heat, and the Debye temperatures were deduced and found to be in agreement with the published experimental results. The Debye temperatures are 118 K for hydrogen and 114 K for deuterium. For hydrogen the Debye - Waller factor has been measured by incoherent neutron scattering, and it is found that the mean square displacement of the hydrogen molecules is 0.48 $Å^2$. The nearest-neighbour distance is 3.75 Å. In the harmonic approximation the Debye - Waller factor is given by $2w = 1/3\ \varkappa^2 \ \langle u^2 \rangle$ where $\langle u^2 \rangle$ is the mean square displacement of the molecules and is found from the slope of the line e^{-2w} vs $\varkappa^2$ in the logarithmic plot in fig. 12.

Large single crystals of solid hydrogen were grown, and a study of the anharmonic effects in hydrogen has been initiated.

Molecular Dynamics of p-$C_6D_4Cl_2$

(J. Kjems and P.A. Reynolds)

A sample of deuterated paradichloro-benzene was produced, and a single crystal in the high temperature β-phase was grown from the melt. The crystal structure is triclinic with only one molecule in the unit cell. This simplified the study of the lattice vibrational modes in that only three acoustic and three librational branches had to be determined. The lattice modes are sufficiently separated in frequency from the internal modes in the molecule so that no mixing occurs. The measurements were performed on the MARX spectrometer. All branches were obtained for phonons propagating along either of two of the directions of the basis vectors in the cell in reciprocal space at room temperature, and all but one from the supercooled sample at 90 K. Anharmonic effects cause shifts in the frequencies of the branches up to 50% on cooling, and by a linear extrapolation to 0 K only the harmonic part of the real potential was deduced. The extrapolated dispersion curves were compared with model calculations carried out on the basis of the Pawley model and using a modified version of his original computer program. The parameters used were derived from experimental data for other aromatic compounds independently of our data. The calculations and the extrapolated experimental points agree reasonably well as it is seen from fig. 13, and it is concluded that no forces other than those of van der Waals nature are significant in the chlorobenzenes, and that crystal potential parameters to a reasonable accuracy are transferable within this group of components.

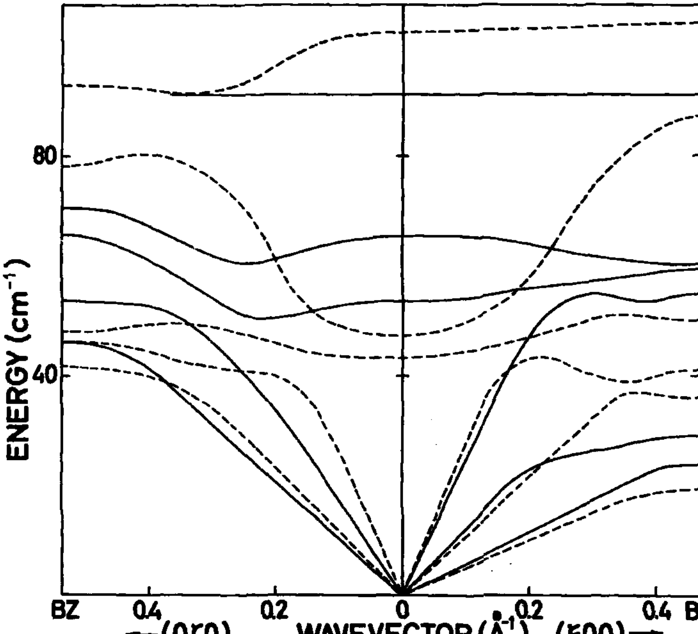

Fig. 13. Extrapolated experimental (full curves) and calculated (dotted curves) dispersion curves for the lattice modes in the β-phase p-$C_6D_4Cl_2$.

Structure of Amorphous Ice

(J. Wenzel, C. Linderstrøm-Lang, and S.A. Rice, University of Chicago)

We have begun an investigation of the structure of amorphous ice as determined by neutron diffraction. It is hoped that its structure is similar to that of liquid water, and that a study of its properties will permit a separation of the structural and dynamic contributions to the properties of liquid water.

Amorphous ice is a low-temperature, metastable, solid phase of water with no long-range order. It is prepared by spraying water vapour onto a cold surface. Conditions for preparation and stability have been studied recently by Olander and Rice (to be published) who concluded that previous workers had prepared impure amorphous ice with crystal nuclei in appreciable concentration. They prepared thin (50 micron) samples at 65 K and below, and determined that they were pure by x-ray diffraction.

Their work was extended by designing and building a cryostat for preparation of large amorphous ice samples which are suitable for neutron diffraction experiments. With this cryostat water vapour was deposited onto a liquid helium-cooled aluminium plate at a rate of 3 mg/h. The final sample was approximately 4 cm in diameter and 1 mm thick. Preliminary measurements of the diffraction spectrum of amorphous heavy water were taken, and they confirm that the samples prepared were amorphous. At present measurements of the diffraction spectrum are being made over a larger Q range using a triple-axis spectrometer (The third axis means only elastically scattered neutrons are counted. This makes corrections for background radiation easier and allows a more accurate determination of the structure factor). When they have been completed, the structure factor S(Q) will be calculated and compared with the structure factor of liquid water. In addition, S(Q) may be Fourier-transformed to yield the radial distribution function of amorphous ice.

In connection with the above experiment a random network model of amorphous ice is being developed; this may also serve as a useful model for the structure of liquid water. The model incorporates Pople's idea of a distorted or bent hydrogen bond and the known tetrahedral coordination in crystalline ice and is used to computer-generate a random network of water molecules. Thus far a two-dimensional random network of zero volume has been generated. It will be extended to three dimensions and will include water molecules of finite volume. When completed, it will yield a radial distribution function which may be compared with the experimental radial distribution function of amorphous ice or which may be Fourier-transformed and compared directly with the structure factor.

Neutron Spectroscopic Method for Structural Studies

(B. Buras and B. Lebech)

A fixed scattering angle neutron method for structural studies of powdered crystals was proposed and checked experimentally. In this method a collimated polychromatic neutron beam is scattered under a fixed angle by a powdered crystal sample, and the wave length distribution of the elastically scattered neutrons is measured by means of a single crystal analyser.

The first neutron patterns obtained by this method are encouraging, in particular with respect to the good resolution for large interplanar spacings. The method might be useful for structural studies in samples under high pressure.

Moving Single Crystal Analyser

(B. Buras and J. Kjems)

It has recently been suggested [1] that a single crystal moving with a velocity h/2md (h - Planck constant, m - neutron mass, d - interplanar spacing) perpendicular to the reflecting plane might serve as a wave length analyser of neutrons travelling parallel to the reflecting plane. This suggestion was proved experimentally using mica crystals (d ~10 Å) mounted on a rotating disk (22680 rpm.; ~200 m/s peripherical velocity), and good agreement between calculated and measured angles of reflection and neutron wave lengths was found.

2. PLASMA PHYSICS

Magnetically Driven Shock Experiment

(C. T. Chang)

In order to study the causes of the velocity limitation of the current sheet, the parameter range of the experiments was extended. Thus in discharges of high voltages (up to 16 kV) and low pressures (down to 20 μ in Ar), the various possible causes were investigated.

Experimental results indicated that the erosion of the insulator end wall definitely plays no important role in our case, while the Hall effect and the effect of the electrode wall friction [43, 44] phenomenologically could equally well explain the observed velocity-limitation of the current-sheet.

Since the presence of a Hall current will affect the uniformity of the flow field, further experiments are planned to study its relative importance.

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[1] B. Buras and T. Giebultowicz, Acta Crystallographica A (in print).

Rotating Plasma Experiment (Puffatron)

(A.H. Sillesen, O. Rasmussen)

The energy analyser for neutral particles was further developed. A good signal to noise ratio was obtained for an energy range of 0.1-5 keV. With this instrument the ion energy distribution in the puffatron during the ionization phase was investigated. The results showed the expected behaviour of the ion energy distribution curve up to a peak corresponding to the E/B velocity of the rotating plasma, but above that peak it also shows a tail of high energy ions which might be associated with an instability driven by the initial cross field current. Because the ionization period is short (1 μsec) in the puffatron, the neutral particle analyser is also able to separate contributions from different masses because of their different transit times. In this way it was seen that 10-20 discharges at the beginning of a series are necessary before a clean hydrogen discharge is obtained.

Solid - Plasma Interaction

(C.T. Chang, A.H. Sillesen, H. Sørensen, and F. Øster)

Injection of frozen hydrogen pellets in a plasma is an attractive way of fuelling a future dc fusion reactor. However, the pellets can only penetrate into the interior of the plasma, if they are screened from the very hot plasma. Very little is known about the solid - plasma interaction. In view of the importance of the fuelling problem we started studies of the screening problem.

It has been suggested that electrostatic [1] and magnetic [2] screening might be theoretically possible. A magnetic screening model (suggested by D. Rose [2]) was studied theoretically [3]. It was for instance found that magnetic screening is possible, but marginal, for typical stellarator-reactor plasmas. It was also found, however, that experimental studies in medium temperature plasmas may give useful information about this model and about the screening problem in general.

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[1] L. Spitzer, D.J. Groove, W.E. Johnson, L. Tonks, and W.F. Westendrup, NYO-6047, pp. 196-229 (1954).

[2] D.J. Rose, private communication.

[3] Internal note.

Fig. 14. A hydrogen pellet photographed with an exposure time of 1 μs while interacting with the plasma. The pellet moves with a velocity of 10m/s towards the upper left corner along the straight line shown in the picture. The plasma rotates counterclockwise with an azimuthal velocity of 0.3 m/μs.

A search for possible screening in a magnetized plasma was started with the puffatron machine. A hydrogen pellet launcher was borrowed from the Culham Laboratory and put into operation. Tests show that the 1/4 mm pellets are launched with a velocity of 10 m/s and an angular spread of ~30 mrad. The pellet launcher was installed at the puffatron machine very recently. Fig. 14 shows an image converter picture of a pellet interacting with the rotating plasma.

The shock tube may also be used for studying the solid - plasma interaction. Experiments have shown that a current-free plasma region can be obtained in the shock tube. After travelling along the electrodes, the current sheet will stop approximately 10 cm beyond the ends of the electrodes. The emerging shock, however, continues for another 10 cm as a current-free plasma.

Studies of the fundamental interactions between solid hydrogen and the different constituents of a fusion plasma environment are being planned.

Holographic interferometric techniques will be used in these solid - plasma interaction studies. In a master's thesis work (by Steen Hanson) the techniques were investigated, and preliminary tests in connection with the shock-tube were successful.

Quiescent Plasmas

(S.A. Andersen, G.B. Christoffersen, V.O. Jensen, P. Michelsen, L. Prahm, and D. Twomey)

A measurement of the charge-exchange cross section for the process $Cs^{+} + Cs \rightarrow Cs + Cs^{+}$ was finished. The cross section was measured at low energies (~ 2 eV), good resolution was obtained by letting all charge exchange processes take place in the plasma in the Q-machine, i.e. at the same potential, the plasma potential. The result is $\sigma = 0.6 \cdot 10^{-13} cm^{2} \pm 20\%$ [39].

The work with the electrostatic energy analyser has resulted in the development of a small analyser. This analyser is cylindrical with a diameter of 2 mm, i.e. comparable to the gyroradius of the ions. The disturbance of the plasma due to the analyser is therefore small, and the ion velocity distribution in a double-ended Q-machine can be measured. The energy resolution is not as good as that obtained with the big analyser. However, it is possible to measure the main features of the distribution function [60].

The propagation properties of small ion acoustic perturbations were studied experimentally and theoretically. These perturbations are initiated in the Q-machine with an electrically oscillating grid. Use of the Vlasov equation requires knowledge of the perturbed ion velocity distribution function at the grid g(v). Measurements with our electrostatic analyser showed that both the shape and the size of g(v) are drastically changed with various parameters [46].

On the basis of the linearized quasi-neutral Vlasov equation we calculated the density perturbations n(x, t) and the perturbed ion velocity distribution function f(x, v, t) for ion acoustic waves. The damped waves obtained when the steady-state ion velocity distribution, $f_o(v)$, is single-humped, are also seen by experimental measurements [47]. If, on the other hand, $f_o(v)$ is an unstable, double-humped distribution function, growing ion-acoustic waves are found [61]. An essential parameter is the ratio between the electron temperature and the ion temperature, T_e/T_i. We showed that it is possible to raise T_e in a Q-machine by means of a high frequency field.

The main conclusions of the numerical studies of the Vlasov-equation - used to calculate the propagation of grid-excited pulses and waves for different g(v) functions and for different values of T_e/T_i - are: For $T_e \sim T_i$ as in most Q-machine experiments, the results are so close to those obtained in the freely streaming case ($T_e = 0$) that it is very difficult to perform experiments that clearly demonstrate collective interactions [51].

Preliminary investigations, however, show that for $T_e > T_i$ the collective interaction causes an "interference" like pattern in the perturbed ion velocity distribution function $f(x, v, t)$ of the ion acoustic wave. This effect should be detectable with the analyser for $T_e \sim 3T_i$.

A collective interaction was demonstrated in the propagation of a step like perturbation, and the results are in good agreement with the theoretical calculations.

A theoretical explanation of the mechanism that causes the heating of the solar wind ions was proposed: At about 1 A.U. from the sun the solar wind passes through a neutral background of hydrogen. The atoms in this background become ionized partly by charge exchange processes, partly by photo ionization. The ions formed are approximately at rest; together with the solar wind ions they form a double-humped velocity distribution function which is unstable to various instabilities. In the reference system following the solar wind the instabilities transfer energy from the ions formed by ionization to the wind ions and thereby heat the wind [14].

3. NUCLEAR PHYSICS

Fission Studies

(V. Andersen and C.J. Christensen)

An experiment to look for the production of the fission isomer of ^{236}U through an (n, γ) reaction on ^{235}U is being installed at the DR 3 reactor. This 100 ns isomer is known to be formed by (d, p) reactions on ^{235}U. Several groups at other laboratories have searched for the $^{235}U\ (n, \gamma)\ ^{236}U$ production of the isomer. Only one group claims to have seen it, and we find the evidence somewhat uncertain.

We plan to look for the de-excitation of the ^{236}U compound nucleus through a γ-cascade followed by a delayed fission.

4. RADIATION DAMAGE

Stopping Power of Metals to Protons

(H. Sørensen and H.H. Andersen (University of Århus))

The energy range of the earlier proton stopping power measurements (2.25-12 MeV) was extended up to 18 MeV in a series of measurements at the new tandem van der Graaf of the Niels Bohr Institute.

The previously used apparatus (a calorimetric method[1]) was used again. During the measurement the particles penetrate the target and are subsequently stopped in a thicker gold plate. The heat evolved in target and gold plate is measured. At the higher energies, the particles can penetrate the coulomb-barrier of either the target or the gold-nuclei. Thus a variety of nuclear reactions can take place. These will influence the heat evolved and consequently necessitate new types of corrections. These corrections are not too accurate, and they will at higher energies determine the overall accuracy of the measured stopping power. In the special case of protons stopped in uranium the correction for fission in the target is important already at 10 MeV, and it reaches 3% at 18 MeV.

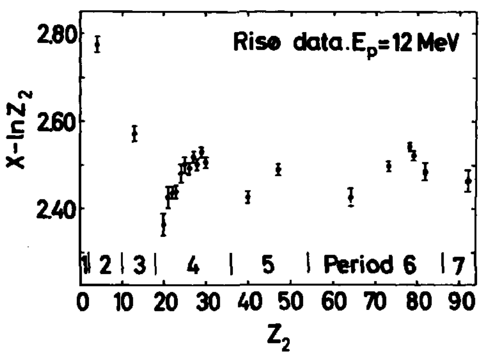

Fig. 15. The relation between stopping power parameters ($x-\ln z_2 = \ln J+\frac{C}{z_2}-\ln z_2$) and the atomic number z_2 for Risø data at a proton energy of 12 MeV.

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[1]) H.H. Andersen, A.F. Garfinkel, C.C. Hanke, and H. Sørensen, Mat. Fys. Medd. Dan. Vid. Selsk. 35, No. 4 (1966).

Proton stopping powers in Al, Cu, Ag, and Au were obtained up to 18 MeV with an accuracy of 0.4% [1]. The agreement with the old data up to 12 MeV was excellent.

The stopping power in Pb and U was measured with accuracies of 0.6% and 0.8% respectively [1]. Pb and U are among the heaviest available target materials. They serve to extend the general trend shown in our survey of the elements and to elucidate the oscillatory behaviour of the mean excitation potential I. This is demonstrated in fig. 15 which shows $X - \ln Z_2 = \ln I + C/Z_2 - \ln Z_2$ versus Z_2 plotted for all the elements we have studied. The new data for $Z_2 = 82$ and 92 are included.

5. METEOROLOGY

Experimental Equipment

(N.E. Busch, L. Kristensen and S.E. Larsen)

A variety of techniques are utilized in investigations of the turbulence structure. Some of these techniques are: Sonic anemometry, hot-wire thermometry, quartz crystal humidiometry, and Lyman-Alpha humidiometry. To facilitate the processing of routine data from the big tower, which has been equipped with new and improved sensors, a thirty-channel digitizer for automatic sampling of climatological data was developed. Each channel is basically a counter with the counting time adjustable from 5 ms to 1800 s. The resolution in each count is 1 in 4096. Twenty-four channels are supplied with analogue to frequency converters, which makes it possible to sample analogue signals as well as frequency-modulated signals. The data are recorded on a nine-track digital magnetic tape recorder. The construction of a 48 m movable tower has just been completed. The data processing system for this tower will be installed in a van during the spring of 1972. The system consists of an automatic sampler capable of sampling sixty channels simultaneously at a rate of 200 times per second, and an on-line digital computer.

On the basis of experience gained during the 1968 Kansas experiment a second generation three-dimensional hot-wire probe was developed and improvements introduced in the analogue recording system.

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[1]) to be published.

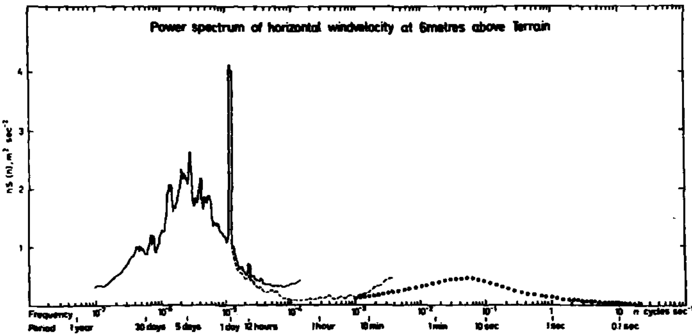
Climatology

(L. Kristensen, H.A. Panofsky, and E.L. Petersen)

For more than 14 years, hourly readings of wind speeds and directions, temperatures, humidities, pressure, precipitation, etc. have been made essentially uninterruptedly. This material, which has been reduced to a computer oriented form, is being studied in detail and applied in pursuit of a variety of goals.

The analysis is partly in terms of probability distributions of the measured quantities (and derived quantities such as stability parameters, inversion heights, etc.), partly in terms of power spectra and cross spectra.

The general existence of a spectral energy gap between synoptic phenomena and turbulence was verified (see fig. 16). Experiments continue



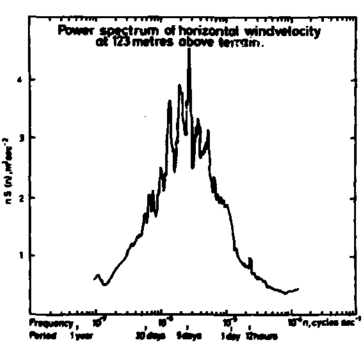


Fig. 16. Power spectra of the horizontal wind velocity at two different heights above the ground.——Hourly measurements of ten-minute averages taken at Risø, 1958-1967. ------ Twenty-seconds averages measured at two-minute intervals at Risø in five weeks in 1971. The high frequency parts of the two spectra are influenced by aliasing. ······ Turbulence spectrum measured in Kansas in 1968, based on analogue analysis of twenty-five hourly records.

in order to investigate the nature and frequency of occurrence of mesoscale phenomena which may fill up the gap.

Wind speed spectra close to the ground show a pronounced daily peak. The peak is absent at a height of 123 metres (see fig. 16).

Gust statistics are being investigated by means of gust indicators which make it possible to record automatically the mean wind velocity and the peak velocity as measured over consecutive 2-minute periods.

An analysis of the wind profiles revealed a characteristic variation of wind with height depending on wind direction, i.e. on the character of the up-stream surface. Thus a double discontinuity in surface roughness shows up as a double "kink" in the wind profile (see fig. 17).

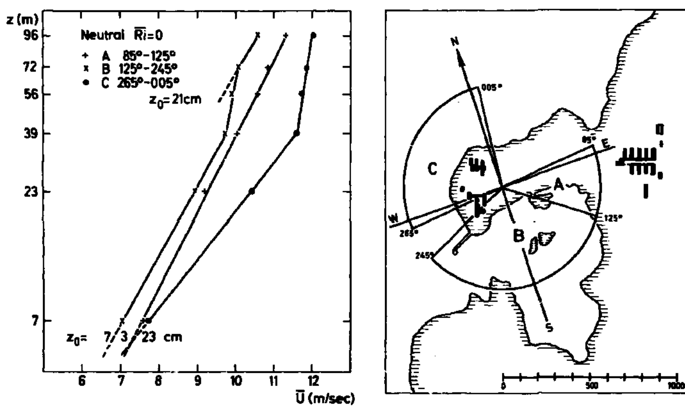


Fig. 17. Mean wind profiles for hydrostatical neutral air, measured at Risø with the wind coming from different angular sectors as shown on the map of Risø. The surface roughness changes are clearly reflected by "kinks" in the profiles, the characteristics of which depend on the wind direction.

1968 Kansas Experiment

(N.E. Busch and S.E. Larsen)

In the summer of 1968 the meteorology group participated in an experiment directed by the Boundary Layer Branch of Air Force Cambridge Research Laboratories. The aim of the project was a comprehensive understanding of the turbulent transport mechanisms in the lowest thirty metres of the atmosphere over horizontally homogeneous terrain.

The analysis of twenty-five hours of turbulence data (velocity components u, v, w, and temperature T) measured at a height of 5.7 metres by means of hot-wire anemometry and resistance-wire thermometry has now been essentially completed. The most surprising thing about the results is probably the apparent abruptness with which the low-frequency part of the flow field changes when the hydrostatic conditions shift from slightly stable to slightly unstable. Another interesting result is that in both of the stability regimes the spectral ratios S_w/S_u and S_w/S_v are functions of $(\lambda_{mf}/\lambda_{mN})f$ only, where f is the reduced frequency, λ_m is the wavelength at which the logarithmic spectrum of vertical velocity has its peak, and λ_{mN} is the value of λ_m under hydrostatically neutral conditions (see fig. 18).

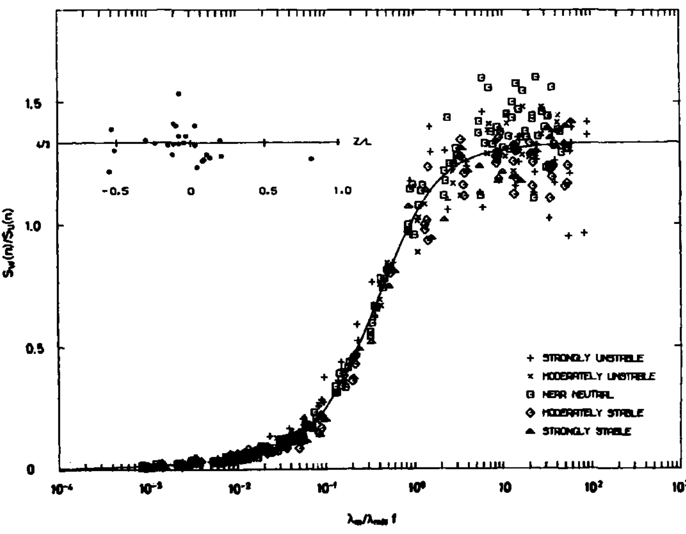


Fig. 18. The measured ratios of the vertical velocity spectrum, $S_w(n)$, and the longitudinal velocity spectrum, $S_u(n)$, plotted versus the scaled reduced frequency $\frac{\lambda_m}{\lambda_{mN}}$. Also the ratios of the smoothed spectra in the initial subrange are plotted versus the stability parameter z/L.

Air - Sea Interaction

(L. Kristensen and S. E. Larsen)

The one-hour long runs were recorded over the shallow water of Roskilde Fjord. The position of the platform was chosen such that an unobstructed fetch of 4 to 8 kilo netres was obtained. The height of observation was 2 metres. The instruments used were: Cup anemometers, quartz thermometers, three-dimensional sonic anemometers, Lyman-Alpha humidiometers, hot-wire anemometers, and fine-wire thermometers.

The data were recorded by FM methods as well as digitally on magnetic tape. Technical difficulties with the newly developed digital system caused a number of problems in connection with retrival of data from the tapes. These problems have now been solved, and the data are being analysed.

Analysis of Stochastic Data Series

(N.E. Busch, J.A. Dutton, L. Kristensen, S.E. Larsen and E.L. Petersen)

A common approach to the reduction of measurements of turbulent velocities is the computation of energy or variance spectra. Such spectra are based upon Fourier transformations and are designed to reveal the frequency decomposition of energy or variance in data series. Current versions of this spectral technique apply when the record may be considered a realization of a stationary process. The effects of aliasing, averaging, and smoothing in digital computation were investigated, and an analogue method for spectral analysis was developed for records from stationary ensembles.

Often, however, the stationarity assumption is untenable. We explored the consequences of the proper orthogonal decomposition theorem in the case of non-stationary processes. This theorem yields an empirical set of orthogonal functions for the description of the autocovariance function and for the measured data records themselves. Techniques derived from this approach were applied to climatological data as a means of discovering the precise structure of the daily variation in temperature (42, 52, 53).

The proper orthogonal decomposition theorem was used as the foundation for a definition of evolutionary energy spectra suitable for non-stationary ensembles of data records of finite length. Computational details are being resolved in the process of applying the new technique to climatological data.

Applied Meteorology

(N. E. Busch, L. Kristensen, S. E. Larsen and E. L. Petersen)

During this year, as during earlier years, the meteorology group undertook a number of tasks of an applied nature.

1. Site Evaluation and Dispersion Modelling. The group is developing a meteorological sensor-array and data compilation system for use in site evaluation projects. The climatological data available at Risø are well suited as a basis for a dose-climatology for routine as well as accidental releases of radioactive material.

Ten years of data have been delivered to AB Atomenergi, Studsvik, for this purpose.

2. Development and Testing of Meteorological Instruments. In cooperation with the firm of G. Schultz new cup anemometers and wind vanes were developed. These instruments are now commercially available. In collaboration with the Metallurgy and the Chemistry Departments (Risø) work was started with a view to the use of carbon reinforced plastics in light-weight, but sturdy, meteorological instruments (e. g. light cup anemometers). Together with the Electronics Department (Risø) the group is investigating the feasibility of an atmospheric LASER velocity meter employing Doppler shift of backscattered light.

3. Air Pollution. Some time was spent advising private companies as well as government agencies. By far the most substantial amount of time used on pollution activities was invested in the work leading to publications Nos. 3 and 8, Forureningsrådet - Sekretariatet (The Pollution Council), 1971 (in Danish).

4. Dynamic Effect of Wind on Structures. In connection with a revision of the Danish Building Code, theoretical and numerical studies were undertaken concerning this important problem. A preliminary report was delivered to the Building Code Committee.

5. Characteristics of Extreme-Wind Probe. The wind loads in the Danish Building Code are based on extreme value statistics derived from 7 years of measurements at characteristic locations [1]. The measurements were performed by means of Pitot probes arranged on wind vanes.

Using hot-wire anemometers and fast-responding cup anemometers the response characteristics of this Pitot/vane-system were established.

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[1] M. Jensen og N. Frank, The Climate of Strong Winds in Denmark (Danish Technical Press, Copenhagen, 1970).

6. LIQUID N_2-AND He- PLANTS

The production of liquid N_2 and He was 120.000 litres and 12.000 litres respectively. Out of this 6.000 litres of liquid He were delivered to laboratories in Copenhagen.

7. EDUCATIONAL ACTIVITIES AND PUBLICATIONS

Lectures (lecturer, subject, institute)

J. Als-Nielsen, Nuclear Physics (lecture series). The Technical University of Copenhagen.

H. Bjerrum Møller, Neutron Diffraction from Magnetic Systems, (8 lectures). Nordic Summer School on Magnetic Properties of Matter, Vålådalen, Sverige (Juni 1971).

B. Buras, Neutron Diffraction by Moving Lattice:

1) University of Copenhagen (June 1971).
2) Österreichische Chemische und Physikalische Gesellschaft, Vienna (November 1971).

B. Buras, X-Ray and Neutron Spectroscopic Methods for Structure Studies:

1) University of Vienna (November 1971).
2) Danish Solid State Physical and Chemical Society (December 1971).
3) The Technical University of Copenhagen (December 1971).

N.E. Busch, On the Use of Eigenfunctions in Meteorology and Geophysics. University of Hamburg (June 1971).

N.E. Busch, The Earth's Boundary Layer. Sandia Laboratories - Research Colloquium, New Mexico (December 1971).

N.E. Busch, Scales and Other Aspects of Turbulence in the Atmospheric Boundary Layer. AFCRL-Research Colloquium, Boston (December 1971).

C.T. Chang, Velocity Limitation of the Current Sheet in a Magnetically Driven Shock Tube:

1) Institut für Plasmaphysik, Kernforschungsanlage Jülich (October 1971).
2) Kungl. Tekniska Högskolan, Stockholm (June 1971).

O.W. Dietrich, Neutron Scattering from Rotons in Liquid Helium:

1) Brookhaven National Laboratory, U.S.A. (March 1971).
2) Harvard University, U.S.A. (October 1971).
3) Iowa State University Ames, U.S.A. (November 1971).
4) Argonne National Laboratory, U.S.A. (November 1971).
5) Duke University, Durham, N.C., U.S.A. (December 1971).
6) Ford Motor Company, Detroit, Mich., U.S.A. (December 1971).
7) Bell Telephone Laboratory, N.J., U.S.A. (December 1971).

O.W. Dietrich, Critical Phenomena in EuO and EuS, Massachussetts Institute of Technology, U.S.A. (October 1971).

J.A. Dutton, Global Thermodynamics and Maintenance of the General Circulation. The Institute for Theoretical Meteorology, Copenhagen (November 1971).

J.A. Dutton, Energetics in the Isentropic View. The Institute for Theoretical Meteorology, Copenhagen (December 1971).

J.A. Dutton, A New View of the Fundamental Aspects of the Atmosphere's Large-Scale circulation. The Laboratory for Applied Mathematics and Mechanics, the Technical University of Copenhagen (December 1971).

V.O. Jensen, Plasma Physics (lecture series). The Technical University of Copenhagen.

V.O. Jensen, Collective Interaction in Propagation of Ion Waves in Q-Machines:

1) Plasma Physics Division, Royal Inst. of Technology, Stockholm (February 1971).
2) Uppsala University (February 1971).
3) ESRIN, Frascati, Rome (May 1971).
4) Gordon Conference, Andover, New Hampshire (July 1971).
5) Aarhus Universitet (November 1971).

L. Kristensen, Spectral Analysis of Stationary Time Series. Danish Geophysical Society, Copenhagen (April 1971).

S. Larsen, Spectral Analysis of Stationary Time Series. Danish Geophysical Society, Copenhagen (April 1971).

Conference Papers

1. J. Als-Nielsen, Neutron Scattering from the Heisenberg Ferromagnets EuO and EuS. Danish Solid State Physical and Chemical Society, Copenhagen (February 1971).

2. J. Als-Nielsen, Phase Transitions and Neutron Scattering. First European Conference on the Physics of Condensed Matter, Florence (September 1971).

3. J. Als-Nielsen, Critical Phenomena and Neutron Scattering. Conference on "Critical Phenomena" arranged by Deutsche Bunsen-Gesellschaft für Physikalische Chemie and Société de Chimie Physique de la France, Lindau (September 1971).

4. J. Als-Nielsen, Phase Transitions and Neutron Scattering. Danish Solid State Physical and Chemical Society, Copenhagen (October 1971).

5. S.A. Andersen, V.O. Jensen, and P. Michelsen. Resonance Charge Exchange Cross Section for Cesium measured around 2 eV. Proc. Third Int. Conf. on Quiescent Plasmas, Elsinore (September 1971).

6. N.E. Busch, Weather and Climate Factors in Industrial Site Evaluation with Respect to Air Pollution. Kem-Tek 2 Congress, Copenhagen (November 1971).

7. N.F. Busch, Aims and Goals, Symposium on Air Pollution Turbulence and Diffusion, Las Cruces, New Mexico (December 1971).

8. N.E. Busch and E.L. Petersen, Analysis of Nonstationary Ensembles. Statistical Methods and Instrumentation in Geophysics, Proceedings of the NATO Advanced Study Institute in Norway (April 1971).

9. C.T. Chang, Remarks Concerning the Steady-State Current Sheet Speed in a Magnetically Driven Shock Tube. The Norwegian Gas discharge- and Plasma Physics Symposium, Beitö (February 1971).

10. C.T. Chang, Remarks Concerning the Steady-State Current Sheet Speed in a Magnetically Driven Shock Tube. Euromech Colloquium-29 on High Temperature Gas Dynamics, Institut für Allgemeine Mechanik, T.H. Aachen (October 1971).

11. G.B. Christoffersen, Measurements of the Perturbed Ion Velocity Distribution at a Wave Exciting Grid. Proc. Third Int. Conf. on Quiescent Plasmas, Elsinore (September 1971).

12. G.B. Christoffersen, V.O. Jensen, and P. Michelsen, Calculations and Measurements of the Perturbed Density and Ion Velocity Distribution. Proc. Third Int. Conf. on Quiescent Plasmas, Elsinore (September 1971).

13. G.B. Christoffersen, Experimentelt Arbejde ved Q-maskinen i 1970. The Norwegian Gas discharge- and Plasma Physics Symposium, Beitö (February 1971).

14. N. D'Angelo and V.O. Jensen, Heating of the Solar Wind. Conference on Cosmic Plasma Physics, Frascati, Italy (September 1971).

15. O.W. Dietrich and L. Passell, Neutron Scattering from Rotons in Liquid Helium. Gordon Conference on "Quantum Solids and Liquids", Beaverdam, Wisc, U.S.A. (August 1971).

16. O.W. Dietrich, J. Als-Nielsen, and L. Passell, Exchange Interaction in EuO and EuS. Magnetism and Magnetic Materials, Chicago, U.S.A. (November 1971).

17. P. Fischer, A. Furrer, H. Heer, W. Hälg, P. Schobinger-Papamentellos, A. Niggli, O. Vogt, J.K. Kjems, and B. Rainford, Neutron Scattering by Nd-Va Compounds; Magnetic Properties and Crystal Field Effects. Conference on Rare Earths and Actinides, University of Durham, England (July 1971).

18. M.B.M. Harryman, P.A. Reynolds, J.W. White, and J.K. Kjems, Density of States Measurements for Phonons in Aromatic Crystals. International Conference on Phonons, Rennes, France (August 1971).

19. V.O Jensen, Collective Interaction and Freely Streaming Ions in Density Perturbation and Waves in Q-Machines. Proc. Third Int. Conf. on Quiescent Plasmas, Elsinore (September 1971).

20. J.K. Kjems, P.A. Reynolds, and J.W. White, Density of States Measurements for Phonons in Aromatic Crystals. Int. Conf. on Phonons, Rennes, France (July 1971).

21. L. Kristensen, The Effect of Aliasing, Averaging, and Smoothing in Digital Spectrum Analysis. Statistical Methods and Instrumentation in Geophysics, Proceedings of the NATO Advanced Study Institute in Norway (April 1971).

22. S. Larsen, Spectral Analysis Based on Analog Technique. Statistical Methods and Instrumentation in Geophysics, Proceedings of the NATO Advanced Study Institute in Norway (April 1971).

23. B. Lebech, P. Fischer and B. D. Rainford, The Magnetic Structures of CeSb. Conference on Rare Earths and Actinides, University of Durham, England (July 1971).

24. B. Lebech and B. D. Rainford, Magnetic Field Dependence of the Magnetic Structure of Neodymium. Conference on Rare Earths and Actinides, University of Durham, England (July 1971).

25. P. A. Lindgård and J. Gylden Houmann, Anisotropic Exchange Interactions in Rare Earth Metals. Conference on Rare Earths and Actinides, University of Durham, England (July 1971).

26. P. Michelsen, Teoretisk arbejde ved Q-maskinen i 1970. The Norwegian Gas discharge- and Plasma Physics Symposium, Beitö (February 1971).

27. P. Michelsen, A Small Electrostatic Energy Analyser. Proc. Third Int. Conf. on Quiescent Plasmas, Elsinore (September 1971).

28. P. Michelsen and L. P. Prahm, Propagation of Ion-Acoustic Waves in a Plasma with a Double-humped Ion Velocity Distribution Function. Proc. Third Int. Conf. on Quiescent Plasmas, Elsinore (September 1971).

29. P. Michelsen, Calculation of the Perturbed Ion Velocity Distribution Function in an Ion Acoustic Wave. Meeting in the APS Plasma Physics Division, Madison, U.S.A. (November 1971).

30. M. Nielsen, Inelastic Neutron Scattering Observations in Hydrogen and Deuterium. Conference on Quantum Crystals, Banff, Canada (September 1971).

31. M. Nielsen, Inelastic Neutron Scattering Observations in Hydrogen and Deuterium. Danish Solid State Physical and Chemical Society, Copenhagen (October 1971).

32. H. A. Panofsky and E. L. Petersen, Wind Profiles and Change of Terrain Roughness at Risø. Symposium on Air Pollution Turbulence and Diffusion, Las Cruses, New Mexico, U.S.A. (December 1971).

33. B. D. Rainford and J. Gylden Houmann, Magnetic Excitations in Praseodymium. Conference on Rare Earths and Actinides, University of Durham, England (July 1971).

34. D. Twomey, Propagation Properties of Short Density Perturbations in Q-machine Plasmas with Double-humped Ion Velocity Distribution Functions. Proc. Third Int. Conf. on Quiescent Plasmas, Elsinore (September 1971).

Publications

35. J. Als-Nielsen, J.D. Axe, and G. Shirane, Spin-Wave and Critical Neutron Scattering from Chromium. J. Appl. Phys. 42 (1971), 1666-1671.

36. J. Als-Nielsen, O.W. Dietrich, W. Kunnmann, and L. Passell, Critical Behavior of the Heisenberg Ferromagnets EuO and EuS. Phys. Rev. Lett. 27 (1971), 741-745.

37. H.H. Andersen, H. Simonsen, and H. Sørensen, A Low-Temperature Irradiation Facility for Heavy-Ion Radiation Damage Studies of Metals. Risø Report No. 204 (1971) 59 pp.

38. S.A. Andersen, G.B. Christoffersen, V.O. Jensen, P. Michelsen, and P. Nielsen, Measurements of Wave - Particle Interaction in a Single-Ended Q-Machine. Phys. Fluids 14 (1971), 990-998.

39. S.A. Andersen, V.O. Jensen, and P. Michelsen, Resonance Charge Exchange Cross Section for Cesium measured around 2 eV. In: Proceedings of the Third International Conference on Quiescent Plasmas, Elsinore, 20-24 September 1971. Risø Report No. 250 (1971) 388-394.

40. S.A. Andersen, V.O. Jensen, P. Michelsen, and P. Nielsen, Determination and Shaping of the Ion-Velocity Distribution Function in a Single-Ended Q-Machine. Phys. Fluids 14 (1971), 728-736.

41. R.J. Birgeneau, J. Als-Nielsen, and E. Bucher, Magnetic Excitons in Singlet-Ground-State Ferromagnets. Phys. Rev. Lett. 27 (1971), 1530-1533.

42. N.E. Busch and E.L. Petersen, Analysis of Nonstationary Ensembles. In: Statistical Methods and Instrumentation in Geophysics. Proceedings of the NATO Advanced Study Institute in Norway, Geilo, 13-20 April 1971. Edited by Anton G. Kjelaas (Teknologisk Forlag, Oslo, 1971), 71-92.

43. C.T. Chang, Comments on "Snowplowing in a Plasma Rail Gun". Phys. Fluids 14 (1971), 1819-1820.

44. C.T. Chang, The Effect of Wall Friction On The Current-Sheet Speed of a Magnetically Driven Shock Tube". Plasma Phys. 13 (1971), 1067-1073.

45. C.J. Christensen, A. Nielsen, A. Bahnsen, W.K. Brown, and B.M. Rustad, Free Neutron Beta-Decay Half-Life. Risø Report No. 226 (1971), 57 pp.

46. G.B. Christoffersen, Measurements of the Perturbed Ion Velocity Distribution at a Wave-Exciting Grid. In: Proceedings of the Third International Conference on Quiescent Plasmas, Elsinore, 20-24 September 1971. Risø Report No. 250 (1971), 55-62.

47. G.B. Christoffersen, V.O. Jensen, and P. Michelsen, Calculations and Measurements of the Perturbed Density and Ion Velocity Distribution Function in Grid-Excited Waves in a Q-Machine Plasma. In: Proceedings of the Third International Conference on Quiescent Plasmas, Elsinore, 20-24 September 1971. Risø Report No. 250 (1971), 63-70.

48. O.W. Dietrich and J. Als-Nielsen, Spin Dynamics in Tb Studied by Critical Neutron Scattering. J. Phys. C 4 (1971), 71-79.

49. P. Fischer, A. Furrer, H. Heer, W. Haig, P. Schobinger-Papamentellos, A. Niggli, O. Vogt, J.K. Kjems, and B.D. Rainford, Neutron Scattering by Nd-Va Compounds: Magnetic Properties and Crystal Field Effects. In: Rare Earths and Actinides. Short Papers from the Conference held at the University of Durham, 5-7 July 1971. (Conference Digest No. 3). (Institute of Physics, London, 1971) 206-209.

50. M.B.M. Harryman, P.A. Reynolds, J.W. White, and J.K. Kjems, Density of States Measurements for Phonons in Aromatic Crystals. In: Phonons. Proceedings of the International Conference, Rennes, France, 1971. Edited by M.A. Nusimovici. (Flamarion Médecine-Sciences, Paris, 1971) 209-222.

51. V.O. Jensen, Collective Interaction and Freely Streaming Ions in Density Perturbations and Waves in Q-Machines. In: Proceedings of the Third International Conference on Quiescent Plasmas, Elsinore, 20-24 September 1971. Risø Report No. 250 (1971) 87-94.

52. L. Kristensen, The Effect of Aliasing, Averaging and Smoothing in Digital Spectrum Analysis. In: Statistical Methods and Instrumentation in Geophysics. Proceedings of the NATO Advanced Study Institute in Norway, Geilo, 13-20 April 1971. Edited by Anton G. Kjelaas (Teknologisk Forlag, Oslo, 1971) 1-24.

53. S. Larsen, Spectral Analysis Based on Analog Technique. In: Statistical Methods and Instrumentation in Geophysics. Proceedings of the NATO Advanced Study Institute in Norway, Geilo, 13-20 April 1971. Edited by Anton G. Kjelaas (Teknologisk Forlag, Oslo, 1971), 137-154.

54. B. Lebech and B. D. Rainford, The Magnetic Structures of Praseodymium and Neodymium. J. Phys. Paris 32 No. 2-3, Suppl. (1971) Cl 370 - Cl 371 (= J. Phys. Paris Colloq. 32 No. 1, Pt I (1971) Cl 370 - Cl 371).

55. B. Lebech, P. Fischer, and B. D. Rainford, The Magnetic Structure of CeSb. In: Rare Earths and Actinides. Short Papers from the Conference held at the University of Durham, 5-7 July 1971. (Conference Digest No. 3). (Institute of Physics, London, 1971) 204-205.

56. B. Lebech and B. D. Rainford, Magnetic Field Dependence of the Magnetic Structure of Neodymium. In: Rare Earths and Actinides. Short Papers from the Conference held at the University of Durham, 5-7 July 1971. (Conference Digest No. 3). (Institute of Physics, London, 1971) 43.

57. P.-A. Lindgård, Magnetic Relaxation in Anisotropic Magnets. J. Phys. C. 4, (1971) 80-82.

58. P.-A. Lindgård, Field Dependence of the Spin Wave Energy in Rare-Earth Metals. J. Phys. Paris 32 No. 2-3, Suppl. (1971) Cl 238 - Cl 239. (= J. Phys. Paris Colloq. 32 No. 1, Pt I (1971) Cl 238 - Cl 239).

59. P.-A. Lindgård and J. Gylden Houmann, Anisotropic Exchange Interaction in Rare Earth Metals. In: Rare Earths and Actinides. Short Papers from the Conference held at the University of Durham, 5-7 July 1971. (Conference Digest No. 3). (Institute of Physics, London, 1971) 192-195.

60. P. Michelsen, A Small Electrostatic Energy Analyser. In: Proceedings of the Third International Conference on Quiescent Plasmas, Elsinore, 20-24 September 1971. Risø Report No. 250 (1971) 382-387.

61. P. Michelsen and L. P. Prahm, Propagation of Ion-Acoustic Waves in a Plasma with a Double-humped Ion Velocity Distribution Function. In: Proceedings of the Third International Conference on Quiescent Plasmas, Elsinore, 20-24 September 1971. Risø Report No. 250 (1971) 103-110.

62. M. Nielsen and H. Bjerrum Møller, Lattice Dynamics of Solid Deuterium by Inelastic Neutron Scattering. Phys. Rev. B 3 (1971) 4383-4385.

63. G.S. Pawley, P.A. Reynolds, J.K. Kjems, and J.W. White, A Model Calculation of the Inelastic Neutron Scattering Spectra from Polycrystalline Naphthalene. Solid State Commun. 9 (1971) 1353-57.

64. B.D. Rainford and J. Gylden Houmann, Magnetic Exciton Dispersion in Praseodymium. Phys. Rev. Lett. 26, (1971) 1254-1256.

65. B.D. Rainford and J. Gylden Houmann, Magnetic Excitations in Praseodymium. In: Rare Earths and Actinides. Short Papers from the Conference held at the University of Durham, 5-7 July 1971. (Conference Digest No. 3). (Institute of Physics, London, 1971) 40-42.

66. D. Twomey, Propagation Properties of Short Density Perturbations in Q-Machine Plasmas with Double-humped Ion Velocity Distribution Functions. In: Proceedings of the Third International Conference on Quiescent Plasmas, Elsinore, 20-24 September 1971, Risø Report No. 250 (1971) 95-102.

Degrees, Students etc.

During the period the following member of the staff acquired the following degrees:

Søren Larsen	lic. techn.

The following postgraduate students carried out research at the Physics Department leading to the degree of lic. techn. or Ph.D.:

Kim Carneiro	(solid state physics)
G. Christoffersen	(plasma physics)
Oluf Danielsen	(solid state physics)
Jens Jensen	(solid state physics)
E.L. Petersen	(meteorology)
Lars Prahm	(plasma physics)
O. Rasmussen	(plasma physics)
J. Wenzel	(solid state physics)
P.A. Reynolds	(solid state physics)

The following undergraduates of Danish universities completed master's thesis projects at the department:

Per Bak	(solid state physics)
Leif Birch	(solid state physics)
Steen Hanson	(plasma physics)
Hans Pecseli	(plasma physics)

Eight foreign students sponsored by the IASTE carried out practical work at the department as part of their general training.

8. STAFF OF THE PHYSICS DEPARTMENT

H. Bjerrum Møller (head of department)

G. Stauning
A. Frellsen (office staff)

1. Solid State Physics (Neutron Physics)

University Graduates

J. Als-Nielsen
B. Buras (also at the H. C. Ørsted Institute)
R.J. Birgeneau (visiting scientist 1 April - 1 October)
Kim Carneiro (Ph. D. - student)
O. Danielsen (Ph. D. - student)
O.W. Dietrich (at Brookhaven National Laboratory until 15 December)
J. Gylden Houmann
Jens Jensen (Ph. D. - student)
J. Kjems
B. Lebech
P.A. Lindgård
S. Liu (visiting scientist, also at the H. C. Ørsted Institute)
A.R. Mackintosh (consultant, the H. C. Ørsted Institute, until 1 August)
A.H. Millhouse (research fellow until 31 March)
H. Bjerrum Møller

M. Nielsen

B. Rainford (visiting scientist until 5 April)

P.A. Reynolds (Ph.D. - student)

E. Warming (at University of Cambridge from 1 April)

J. Wenzel (Ph.D. - student)

Technicians

P.E. Bredahl

B.O. Breiting

K. Christensen

Arent Hansen

B. Heiden

L.G. Jensen

S. Jørgensen

W. Kofoed

J. Linderholm

A. Thuesen

2. Plasma Physics

University Graduates

C.T. Chang

G. Christoffersen (Ph.D. - student)

N. D'Angelo (consultant, ESRIN, Italy)

V.O. Jensen

P.K. Michelsen (at Yale University from 1 November)

L. Prahm (Ph.D. - student)

O. Rasmussen (Ph.D. - student)

A.H. Sillesen

H. Sørensen

Dennis Twomey (visiting scientist until 1 November)

F. Øster

Technicians

B. Bordrup

B. Hurup Hansen

M. Nielsen

A. Nordskov

J. Petersen

B. Reher

3. Nuclear Physics

University Graduates

V. Andersen
C.J. Christensen

Technicians

P. Andersen
F. Hansen

4. Radiation Damage

University Graduates

H. Sørensen

Technicians

B. Bordrup
G. Dalsgård
A. Nordskov

5. Meteorology

University Graduates

N.E. Busch
John A. Dutton (visiting scientist from 1 August)
Leif Kristensen
Søren Larsen
E.L. Petersen (Ph.D. - student)

Technicians

J. Christensen
G. Dalsgård
M. Frederiksen
G. Jensen
K. Sørensen

6. Liquid-N_2 and -He Plant

Technicians

John Z. Jensen
Th. Poulsen

The following foreign guest scientists spent several months at the department:

J.A. Businger University of Washington, Seattle, U.S.A.	(Meteorology)
Peter Fischer Wührenlingen, Schweitz	(Solid State Physics)
A. Furrer Wührenlingen, Schweitz	(" " ")
S. Hamberger Culham, England	(Plasma Physics)
H. Kraus Universität, München, Germany	(Meteorology)
L. Lindberg KTH, Stockholm, Sverige	(Plasma Physics)
W.M. Lomer Harwell, England	(Solid State Physics)
H.A. Panofsky, Pensylvania State University, U.S.A.	(Meteorology)
R. Rinaldi University of Edinburgh, Scotland	(Solid State Physics)
S.K. Sinha Ames, Iowa, U.S.A.	(" " ")
D. Sledziewska Warzaw, Poland	(" " ")
G.R. Towers Melbourne, Australia	(" " ")